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THE SPECTRA OF MERCURY.

DISSERTATION

Submitted to the Board of University Studies of the

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Doctor of Philosophy.

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by

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TABLE OF CONTENTS

	Page
Introduction	2
Apparatus	4
Arc-Spectrum	6
Spectrum of Spark in Air	9
Effect of Capacity	9
of Self-Induction	11
of Length of Spark	13
Spectra of Mercury in Tubes	14
Form of Tube	15
Preliminary Experiments	16
Effect of Capacity	18
of Self-Induction	20
of Pressure	21
Air-Lines in Tubes	23
Study of Spectrum from Entire Tube	25
External Electrodes	27
Alternating Discharge	28
Summary of Results	29
Photographs	31-37

INTRODUCTION.

The spectrum of a substance in a vacuum tube assumes different forms as the conditions under which it is observed are made to vary. The discharge through many of the gases has been quite thoroughly studied, as it is affected by temperature and pressure in the tube and by the nature of the discharge.

The fact that mercury is used in most pumps and the great influence which even a very small percentage of its vapor has upon the spectrum of such a gas as hydrogen in a tube, points to the necessity for a detailed study of the mercury spectrum.(1)

Additional weight is added to the above reason by the work of Eder and Valenta, in which they announce their discovery of the band-spectrum and the possibility of breaking this up into a line-spectrum having a vastly greater number of lines than the one formerly known.

Further, since mercury is monatomic, its study should help answer the question as to whether a monatomic substance can have a band-spectrum which can be broken up into one showing lines only.(2)

It may be urged that in the spectrum from a tube, we get the effect of particles thrown off the glass walls and the

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(1) The Effect of certain Impurities in the Spectra of some Gases. P. Levis. Ast.Phys.Journ.X,1899.
(2) Lockyer, Proc. Roy. Soc. XXI.

electrodes, as well as that of the residual gases.

Nevertheless, we know that a small amount of mercury vapor in a tube renders the effects due to the presence of some other gases in the tube small.(1)

Accordingly, in studying the discharge through a tube of mercury vapor, we have conditions somewhat less complex than those usually presented when the spectra given by tubes ~~is~~ are to be investigated.

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(1) The Effect of certain Impurities in the Spectra of Some Gases. P. Lewis. Ast. Phys. Journ. X, 1899.

APPARATUS.

The gratings used were a large concave one of 21 feet radius and a smaller one of 7 feet.

For obtaining the arc-spectrum, a direct current of about 10 amperes was used. The spark, and the discharge through tubes, was obtained from an ordinary induction coil giving a spark 8 cm. long; or from a coil the primary of which carried an alternating current from a Westinghouse dynamo making 130 complete oscillations per second. With no capacity in the secondary, the discharge from this latter coil was an alternating arc. With capacity, it gave a succession of strong sparks. The extreme length obtainable was about 2 cm. Shortening the spark increased the rapidity of the succession, as was evident from the pitch of the note from the discharge.

For the vacuum tubes, German sodium glass was used. Though Jena glass stood heating better, it was more difficult to seal electrodes into and at times it would develop longitudinal cracks, several days after working and at some distance from a joint.

For exhausting, the ordinary forms of mercury pump were used, with drying apparatus, etc. Pressures were read with a M'leod gauge.

Except for rough work, tubes were carefully cleaned and mercury was freshly distilled just before using.

It was found that repeated sparking always raised the

pressure of a tube joined to the pump. This was true, even when the sparking and exhausting were repeated at intervals for several days.

Before sealing off from the pump, the mercury in the tube was boiled and the walls of the tube were heated.

ARC - SPECTRUM OF MERCURY.

Preliminary to a study of the spectra of mercury in tubes, it was deemed advisable to obtain the arc-spectrum. This was attempted by Liveing and Dewar, but they say they found it possible to get comparatively few lines. Of the lines found, but one, $\lambda = 2536.8$, was reversed.

Kayser and Runge,(1) however, seem to have had no difficulty in obtaining many lines from the arc. They give a list of wave-lengths in their papers on the spectra of the elements.

The first attempts to obtain the arc-spectrum of mercury in this investigation met with small success. Carbon poles were used and the lower one was bored out to a depth of about two inches. This positive pole was filled with the sulphide and, in later attempts, with the metal itself. In neither case were more than a few lines obtained, and these were weak compared with those from the poles, even when a small current was used. Only the strong lines given by Kayser and Runge were found. It became clear that enough metal must be supplied so that it could boil off freely from the arc, for sometimes even when the pole was nearly filled, not a single mercury line appeared on the plate.

Finally, a long carbon was bored out and a rubber tube leading to a reservoir was attached to the lower end. This made it possible to keep the mercury at the very top of the

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(1) Kayser and Runge. Die Spectren der Elemente. 4 Abschnitt, 1891. Abhandl. d. Konig. preuss Akad d. Wiss

pole.

The results were satisfactory, a few minutes exposure giving on the plate all the lines found by Kayser and Runge in that region. In the extreme ultra-violet, an exposure of an hour with the large grating gave lines as short as $\lambda = 1872$. In this ultra-violet region, the plates show some of the comparatively weak lines as coming from the entire space between the poles; others are short on the plate, and seem to have come only from near the carbon terminals.

Some of the extreme ultra-violet lines given by Kayser and Runge were not found. Neither did $\lambda = 3305$, of intensity 6, appear on any plate, although a line at $\lambda = 3342$ to which they give an intensity of but 5 came out strongly.

The following additional arc lines were noted.

λ	i	Character.
2400	3	Double; very hazy
2352.5	2	
2341.0	1	
2323.0	1	Hazy
2284.2	2	
2275.5	1	
2259.2	1	Very hazy.
2230 1	1	
2227.9	1	
2197.7	1	
2194.2	1	
2189.2	2	
2186.6	1	
2172.1	1	
2169.2	1	
2001.6	1	
1919.5	1	
1876.0	2	
1872.2	2	

It is difficult to estimate intensities of lines in this region, since the plates show a great deal of continuous spectrum.

THE SPARK SPECTRUM

The study of the spark in air had for its object the investigation of the effects due to changing the conditions of the discharge, and also the determination of the principal air lines which come out in the spectrum of the spark. A comparison, then, of spark plates with those showing the spectrum from tubes will give an idea of the effect due to the residuum of air in a tube.

EFFECT OF CAPACITY.

Using the large coil, a spark was obtained between an upper terminal of carbon and the mercury held in a broad dish. With no capacity in the secondary, this spark took the appearance of an alternating arc, and the spectrum obtained was that of the arc. For example, the line $\lambda = 2967$ comes out very strongly in the arc and is given an intensity 10 by Kayser and Runge in their list. It also comes out strongly in the spark when capacity is used in the secondary. To a neighboring line, $\lambda = 2848$, Kayser and Runge give an intensity of 4 in the arc, but in the spark Eder and Valenta find it of intensity 10. With no capacity in the secondary of the discharge from the large coil, $\lambda = 2967$ still comes out strongly as compared with other arc lines, while $\lambda = 2848$ decreases in intensity to about what it had in the arc.

As the capacity was increased, the hissing discharge became more disruptive in character and the characteristic spark

lines came out; the continuous spectrum also increased, and all the lines became less sharply defined, even when the light was taken from the upper part of the spark, quite away from the surface of the mercury.

The most clear-cut lines were got from the discharge of the small coil before the slit of the large grating, though the exposure was necessarily very long. Using the maximum capacity, the list of spark lines was found substantially as given by Eder and Valenta.[1]

1 Eder and Valenta. Die verschiedenen Spectren des Quecksilbers, Wien., 1894.

EFFECT OF SELF-INDUCTION.

The effect of self-induction in the secondary was also studied.[1] The coil used consisted of 200 m. of copper wire wound in 9 layers of 30 turns each, each turn 6 m.m. from any other. The self-induction was .009 Henry.

Using this coil in the secondary, with capacity, the most noticeable effect on the discharge was the decrease in its violence, owing to the increased period of the oscillations. The general effect on the spectrum lines was to increase their sharpness, the continuous spectrum of the more violent discharge being cut out.

With self-induction in the secondary, the following lines which appear in both arc and spark spectra were reduced to their arc intensity.

λ	Arc i	Spark i.
2820	4	10
2848	4	10
3390	3	8
3544	4	6
3560	4	6
3790	2	8
3984	4	8

1 Helmsalech. Sur les spectres des decharges oscillantes. Compt. Rend. CXXIX, 5, 1899.

Characteristic spark lines like

λ	i
5426	8
5679	8

were cut out entirely. The lines

λ	Arc i	Spark i
5770	10	10
5790	10	10

compared with the line λ = 5461 whose i = 10 in both spark and arc came out very much stronger for self-induction in the secondary. The effect of self-induction in the secondary is, then, to tend to reduce the spark to the arc and to sharpen the lines. As a result of this sharpening of the lines, λ = 3663 and λ = 3131 are found to be double in the spark in air. That the latter was not a reversal was seen clearly by comparing with λ = 2536 where the reversal showed most clearly nearest the negative terminal. With capacity but no self-induction, a very short exposure shows λ = 3650 reversed, and exceedingly broad and hazy. The introduction of self-induction brings out a single sharp line.

EFFECT OF LENGTH OF SPARK.

With a given capacity, that of a bank of six one-gallon jars, a thick spark about 2 cm. long could be obtained, very disruptive and giving a note whose pitch was given by the alternations in the primary of the coil. Shortening the spark raised the pitch of the discharge until for a length of 3 m m the discharge was a sharp, hissing one, to the ear quite like that when no capacity was used, though in appearance it was still a spark. The spectrum of this short spark gave the arc lines and some of those due to the spark. The arc-lines $\lambda = 5770$ and $\lambda = 5790$ came out equally well in both long and short sparks, while the characteristic spark-lines $\lambda = 5426$ and $\lambda = 5679$ each of intensity 8, came out relatively much stronger in the long than in the short spark.

With self-induction in the secondary, the long and short sparks gave the same lines. It was thought that by comparing the lines obtained from a very long and from a very short spark, a shift might be observed.[1] The very great broadening of the lines in the former case made it impossible to make reliable micrometer settings. The self-induction in the secondary made the lines much less hazy, but also lessened the violence of the discharge.

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1 Wilsing: Astroph. Journ. X. 1899.

SPECTRA OF MERCURY IN TUBES.

The best work on the spectra of mercury in tubes is that done by Eder and Valenta.[1] They discovered the band-spectrum given by mercury vapor distilling through a capillary. By using capacity in the secondary of the induction coil, these bands were broken up into an immense number of lines.

A more detailed study of the spectra from tubes containing mercury seemed desirable, including the effect of continuously varied capacity and of self-induction; also of change of temperature of the tube and of different forms of discharge.

It seemed well, also, to make direct comparison of plates showing the spectrum of the spark in air with those from tubes whose conditions could be varied. While the coincidence of isolated lines cannot, of course, be accepted as evidence of the effects due to the presence of air in the tube, a group of air-lines appearing on a plate from a tube could be identified with certainty. Some idea could then be obtained of the effect of air as the conditions of the tube were changed.

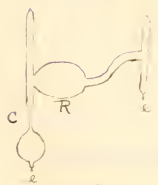
The use of external electrodes would also simplify the conditions.

The first question naturally had to do with the form of tube to be used. The first one tried was similar to that used by Eder and Valenta, and consisted of an ordinary "end-on" exposure with about 6 cm. of capillary, the light passing through a quartz plate sealed on with liquid glass.

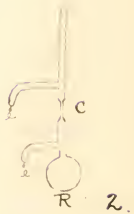
(1) Eder and Valenta Die verscheidenen Spectren des Queckilbers. Wien, 18[illegible]4.

The hardened sodium silicate will stand only a moderate heat and since the work was to be mainly qualitative, the study of the spectra was confined to wave-lengths which glass allowed to pass. A great increase of light came from using a "side-on" tube and since the capillary could be drawn with very thin walls, the shorter wave-lengths were still allowed to pass.

The essential feature of a tube was the possibility of keeping it in a steady state for several hours, if need be. Many forms were made and tried. The spectra obtained could be observed to go through series of changes and could at will be made to repeat these changes. The difficulty was to keep each form constant until it could be photographed. The tubes selected were as shown in 1 and 2.



1.



2.

The electrodes of platinum are at e.

R is a reservoir for mercury.

C is the capillary.

By heating the reservoir, the mercury would distil through

the capillary.

The platinum at the electrodes was covered with mercury.

Upon taking up the study of the tube spectra, it seemed possible that the bands might be due to the glass or to an oxide of mercury formed in the tube.

To free the tubes as far as possible from air, they were kept on the pump for several days and sparked repeatedly. In addition, the mercury was boiled and the whole tube was heated before sealing off.

Such a tube containing no glass of internal diameter less than 8 m m was found to show bands where the discharge left the surface of the mercury, both at anode and kathode; and also in the tube at any point between the electrodes. This seemed to make the use of a capillary, in the main, unobjectionable. Accordingly, a tube of the type 1 had its lower electrode filled until the mercury stood in the capillary. The bands were shown strongest from the surface of the liquid, but appeared throughout the tube. This was without other heat than that of the discharge from the small coil. At the electrodes, the temperature was, perhaps, 70° C,. The pressure in this second tube had been read .1 m m at sealing off. This band-spectrum was identified with that of Eder and Valenta.

Using this same tube, an attempt was made to obtain the line-spectrum of Eder and Valenta by putting capacity in the secondary. To the eye, the only change was that the discharge was not so bright.

Plates including a region between λ = 3900 and λ = 5400 showed one band at λ = 4012 broken up and a few lines to replace it. Capacities were used varying from zero to that of six one-gallon jars, giving no new effect.

The discharge through the tube was made stronger. The tube became hot and a few of the characteristic arc lines came out strongly, the bands disappearing. Capacity brought out a few new lines. Using a weaker discharge, a small flame under the upper reservoir caused the mercury to distil through the capillary. Capacity had little effect except after mercury had condensed in the large tube just above the capillary. Until this flowed down, the capillary discharge became a creamy tint instead of green, and showed a spectrum of many lines, for a moment only. It was found that a tube like 2 gave bands, and by heating the reservoir, the light from the distilling mercury of the capillary could be made to give the line-spectrum for any desired length of time.

A tube with a capillary of 1/4 m m internal diameter abd sealed off at p = .01 m m, was slightly heated and gave bands, which broke up into lines when capacity was used. Too much heat prevented the discharge for a given capacity, as did also too much capacity for a given heating.

With much stronger heating, the discharge would again pass, with a brilliant green color. Capacity made the discharge

dazzlingly bright, its spectrum showing many lines, some of them considerably broadened, and much continuous spectrum. For still stronger heating, the crowd of lines sank back and were merged into the continuous spectrum, only a few of the strongest arc lines standing out slightly.

EFFECT OF CAPACITY.

A tube of the type 2 sealed off at p = .01 m m was heated with a very small gas flame held about 10 cm below the reservoir. After several hours of such heating, the spectrum showed lines or bands as capacity was or was not used in the secondary of the small coil. The conditions were then assumed constant and a series of plates was taken for a capacity varying from zero to the largest that would allow the discharge to pass, that of two one-gallon jars. With a very small capacity, the spectrum was the same as with none, showing the bands. With a 1-pt. jar in the secondary, the most noticeable change was the appearance of λ = 3984 and the broadening toward the violet of the group at λ = 3960. A few new hazy lines appeared in other parts of the spectrum. The line λ = 4216 came out and the band near it weakened. Using a 1-gal. jar and keeping the other conditions constant and the same as for the preceding cases, the bands disappeared entirely, many new lines coming out. With two large jars the effect was but slightly different from that obtained with but one

Chapter IV Conclusion

In general, these results show that a gradual increase of capacity in the secondary changes the spectrum from a band to a line-spectrum. The intermediate conditions may be obtained and photographed.

With a too great capacity, of course no discharge passes, but with the maximum which may be used for a given temperature and current, there is brought out the maximum number of lines in the series of changes from bands to lines and these lines are of greatest sharpness for the given temperature.

With as wide a range of current difference as could be used through the primary of the small coil, the spectra were essentially the same, the discharge differing only in brightness.

EFFECT OF SELF-INDUCTION.

When the air-coil was put in the secondary with capacity, the discharge through the tube decreased in brightness. The change in the spectrum was analogous to that produced in the case of the spark in air. The principal arc lines, like

λ = 3650
3984
4047
4078
4360

were brought out strongly, with considerable continuous spectrum, though in general the lines were sharper than when no coil was used in the secondary. A vast number of lines were cut out entirely or very much weakened.

For a smaller self-induction, fewer lines were cut out.

By the use of such a coil in the secondary, it seems possible, therefore, to reduce the spectrum obtained by breaking up the bands to one showing only the strongest lines of the arc and of the spark in air.

For the above series of plates showing the effects of self-induction and of varying capacity, the same tube was used throughout.

The conditions were kept as nearly constant as possible and the observations were extended over a period of 14 hours.

The tube was then allowed to cool and the spectrum obtained was the same as that before the heating.

PRESSURE.

At comparatively high pressures, the principal arc-lines of mercury are given by the spectra of tubes. The bands appear while the tube contains enough nitrogen to obscure everything else in the ultra-violet. As the pressure is decreased, the amount of heat, in addition to that from the current, needed to give the brilliant discharge grows less and it is consequently easier to get the most abundant line-spectrum. A small capacity gives these lines, and they persist throughout the capillary. The character of the lines also changes, for while with more heat the lines are hazy and shaded on both sides, though more toward the violet, the lines from tubes heated only by a small current are sharp and clear.

Indeed, this sharp line spectrum would scarcely be recognized as related to that obtained at higher pressures. That it is so related was shown by exposing that part of the tube near where the capillary met the larger tube. The anastigmatism of the small grating was such that from the same exposure, the one part of the plate showed bands, the other this sharp-line spectrum.

On slightly heating this tube, the discharge changed from its bluish tint in the capillary to the characteristic bril-

liart one, and with capacity this yielded the same spectrum obtained from tubes sealed off at higher pressure and examined when at higher temperature; also the same lines, so far as eye observation could determine, were seen in tubes sealed off at yet higher pressure and studied when still more strongly heated, but not photographed, owing to the difficulty of keeping their condition constant for any length of time.

The pressures at which the above three sets of tubes were sealed off from the pump were given by the gauge at 1 m m, .06 m m, and .004 m m.

AIR - LINES.

Since the presence of even a trace of mercury vapor in a tube is sufficient to show the lines

λ = 5769
5461
4358

and seems also to reduce the intensity of the lines due to a gas like hydrogen, a comparison was made between plates obtained from a tube and those of the spark in air.

A tube was strongly heated and sparked while on the pump and was sealed off at a pressure of about .003 m m. This tube gave a spectrum of sharp lines. Plates taken with the small grating, using a spark between platinum and mercury showed short lines due to the electrodes, but air lines extending entirely across the plate. A comparison of spark-plates with those from tubes showed the following groups of air-lines on both.

At about λ = 4070
4120
4182
4319
4350
4415
4705

Other lines showed coincidences, but only in cases like the

above where an entire group was the same, could it be said that the air-lines persisted in the tube. The above groups were sometimes of scattered lines; in several cases, they were of fine, sharp lines, close together and equidistant. In every case the character of the group was such as to make certain its identification on the two sets of plates.

A coil in the secondary either very much weakened or entirely cut out every group noted above. When this tube was heated and capacity used in the secondary, the spectrum given was quite distinct from the one previously obtained with capacity but no heating. If the air affected this second spectrum, it was in a way not easily traced. From tubes sealed off at higher pressure and which were not heated except by the discharge, the band-spectrum of mercury was obtained, with only traces of the groups of air-lines. The air-lines seem therefore to come out most strongly at very low pressures and temperatures, but to disappear under conditions giving the bands or the spectrum of many lines. These air-lines reappear in the spectrum from a tube that has been heated until they disappear but which is examined when again cool. The color of the capillary of a tube at a pressure of 1 m m and not heated was purple. For a lower pressure the effect of the nitrogen was lost and the capillary became pink when the discharge first passed, but soon changed to green. When a tube contained capillaries of different sizes, the pink persisted longest in the finest tubes. For a pressure of a few

thousandths of a millimeter, the capillary became blue. But when strongly heated, all tubes showed the characteristic green of the mercury λ 5461, and with capacity gave the dazzlingly bright discharge.

STUDY OF THE ENTIRE TUBE.

Using a plane grating as objective, a complete set of plates was taken from the tube used in studying the changes due to varying the capacity. The advantage of thus photographing the entire tube is obvious, since such a plate gives an image of every part of the tube for each wave-length coming from that part. A small grating held in the hand was found much better than the ordinary direct-vision spectroscope for watching the discharge through a tube so that it might be kept constant during an exposure.

To photograph the entire tube, it was set up at a distance of 4 m from a 5 1/2 inch plane grating. The light from the grating was brought to a focus on a plate about 2 m distant by means of a quartz lens. The region thus obtained was from λ 3200 to λ 5800.

When heated until the brilliant discharge passed, the bands were shown from the capillary and from the large part of the tube between capillary and anode, but not between capillary and kathode, where only a few lines appeared, broad and

hazy in the continuous spectrum. With capacity the line-spectrum appeared, with no trace of bands. In general, the lines persist throughout the tube. One line in the blue comes out in the capillary and the side toward the anode; two others, in the capillary and the side toward the kathode, as does also one in the green.

But few lines continue down to the boiling mercury in the reservoir, those doing so being principally the strong arc-lines.

If the heat is decreased and no capacity used, the discharge becomes less brilliant and bands at $\lambda = 5570$ and $\lambda = 4850$ appear, which did not come out when more heat was used. On putting capacity into the secondary, the band spectrum in the capillary gave way to one showing many lines, though in the large tube toward the anode the bands persisted, as they also did, faintly, toward the kathode.

The effect of self-induction with capacity was to reduce or to cut out entirely throughout the tube many lines brought out by capacity, noticeably in the blue and blue-green and the strong blue $\lambda = 4679$.

Tubes with external electrodes were also used. The form was that of 3. The electrodes were of tin foil, wrapped tightly around the glass and wound with wire. The discharge was not nearly so bright as that obtained from tubes whose platinum terminals made direct contact with the mercury in the bulbs.

3.

The spectra from tubes of different sizes and of different kinds of glass showed bands. One of these tubes was so small that the path of the discharge in the tube was not more than 4 cm. Before sealing off from the pump it was very strongly heated.

In plates showing bands from these tubes were some lines which are probably due to glass, since they do not come out with tubes of the first kind. Attempts to break up the bands from tubes of type 3 were not successful

Plates from these tubes obtained with the plane grating as objective showed the bands on both sides of a globule of mercury in the capillary. Some lines appear on one side of the capillary and but faintly, or not at all, on the other.

ALTERNATING DISCHARGE.

To determine the effect of using the alternating discharge from the large coil, tubes capable of use with large currents were made. With such a discharge, the small capillary was melted at once and one of heavy wall and 1 m m bore showed much continuous spectrum. With a tube of 2 m m inside diameter, the large coil with the bank of six jars in the secondary gave, with 1/50 the time of exposure, a spectrum essentially the same as that got by using the smaller coil.

The air-coil with the above discharge gave results similar to those already described.

The intense heat developed by the heavy alternating current made it impossible to obtain the bands.

That the resistance of a tube of type 2 to the passage of such a discharge is not only at the electrodes but also depends on the length of path to be followed was shown conclusively. The mercury distilling from the electrodes into the reservoir, the length of the path, was increased until the discharge would no longer pass. Refilling the arms of the tube from the reservoir, the discharge again passed. The tube was of the same internal diameter throughout.

RESULTS.

The arc-spectrum was obtained substantially as given by Kayser and Runge and a few additional lines in the extreme ultra-violet were noted.

By increase of capacity in the secondary of a coil giving an alternating discharge, the spectrum changed from that of the arc to one containing the characteristic spark-lines. Self-induction in the secondary of such a coil tends to reduce the spectrum of the spark to that of the arc. A long spark showed lines which were not given by a very short one.

Using a tube, bands were obtained with light directly off the surface of the mercury, both at anode and kathode of a large tube. On heating the tube, the bands disappeared, those in the shortest wave-lengths remaining longest. Capacity breaks up these bands, throughout the tube if it is heated sufficiently; otherwise, only in the capillary and near the kathode where the discharge produces the greatest heating. Self-induction accents the arc-lines at the expense of other lines due to very special conditions. By varying the capacity, it was possible to pass continuously from the band- to the line-spectrum.

For very low pressures, groups of air-lines come out; but are not identified in tubes at higher pressure or in tubes sealed off at low pressure and studied when heated.

The discharge from an ordinary induction coil gave the

same spectrum as that from a very strong alternating current.

The writer takes this opportunity of thanking members of the Department of Physics for assistance given during the progress of this work.

1. Strong alternating spark with neither capacity nor self-induction.

2. Same but with capacity and self-induction.

3. Same but with capacity only.

Photographs showing effect of self-induction on spark in air.

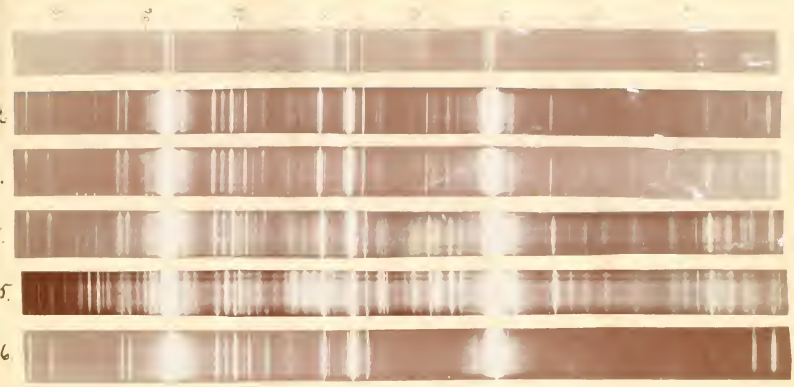
1. Outside, capacity but no self-induction.
   Inside. capacity and self-induction.

2. Same as 1 for λ = 3125.

3. Same as for λ = 3650.

4. Same as 3, but for third order.

5. Outside, long spark.
   Inside, short spark.



Photographs of spectrum of mercury in a tube, to show effects of varying capacity, and of self-induction.

1. Band-spectrum. No capacity used.
2. Capacity one 1-pt. jar.
3. Capacity one 1-qt. jar.
4. Capacity one 1-gal. jar
5. Capacity two 1-gal. jars.
6. Capacity one 1-qt jar and self-induction in secondary.

1.

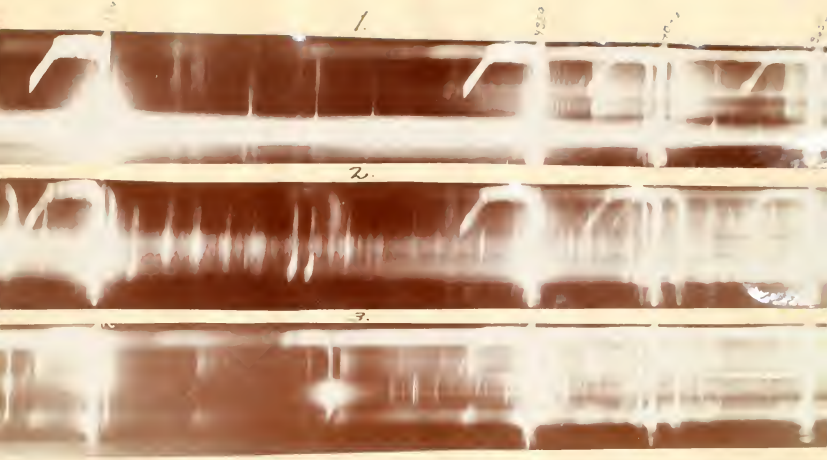
2.

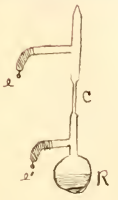
3.

1. Spectrum of spark in air between platinum and mercury

2. Spectrum from tube sealed off at pressure of 0.003 m m. Small capacity in the secondary.

3. Same as 2 but self-induction in the secondary.





Form of tube photographed.
C, capillary.
R, reservoir for mercury.
e e', electrodes connecting with the mercury in each limb of the tube.
For all the above photographs, e' was Kathode.

Spectrum from entire tube of type 2.

1. While strongly heated and with no capacity in the secondary

2. Same, but with capacity.

3. Same as 2, but less strongly heated.

4.

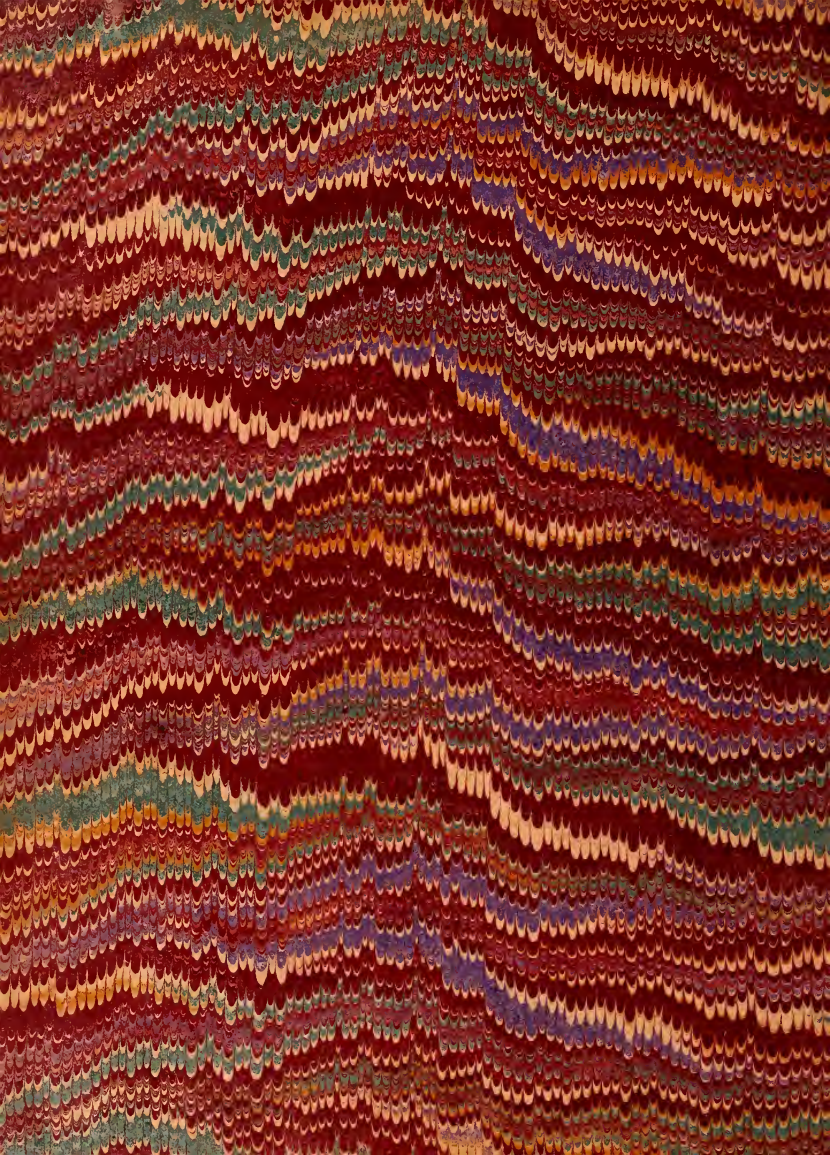
5.

6.

4. Like 1 but short exposure and less heat.

5. " 2 " " " .. . .. .

6. " 3 " " " .. .. . .

BIOGRAPHICAL.

William Rashford Huff was born at Boscobel, Wisconsin, in 1866. He attended the public schools, prepared for college and took a part of his course at Lawrence University, Appleton, Wisconsin, and received the degree of A. B. from the University of Wisconsin in 1889. His collegiate work was done mostly in the departments of ancient languages. After a period of teaching, he studied Mathematics for five quarters at the University of Chicago, and on examination and presentation of a thesis, "Asymptotic Lines on Tores", received the degree of A. M. After teaching Mathematics for three years at the Milwaukee High School, he entered the Johns Hopkins University in 1897, where his principal subject, Physics, was studied for three years. Chemistry and Applied Electricity were subordinates. He was lecture-assistant for the academic year 1899-1900.